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Spreadsheet Applications in Electrical Engineering: A Review*

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Spreadsheets were originally intended for business applications like finance, accounting, and so on. However, the ubiquity and simplicity of spreadsheet programs, in addition to their rich library of built-in functions, plotting capabilities, and other provided utilities, have made them attractive tools for education in engineering as well as other disciplines. This paper presents a brief description of the history of spreadsheets development, and a review of various applications that spreadsheets have in electrical engineering education, especially in the areas of control, electromagnetism, communications and signal processing, electronics, circuits and digital systems, neural networks, power systems, and other fields. The use of spreadsheets in mathematics and other sciences is briefly reviewed, and some possible future trends and applications are suggested.

INTRODUCTION: HISTORICAL EVOLUTION

THE USE OF spreadsheets goes a few hundred years back, mainly in the field of accounting. According to the *Dictionary for Accountants* [1], a 'spread sheet' is a worksheet that provides a two-way analysis of accounting data. It spreads all of the financial numbers such as debits and credits in horizontal and vertical lines respectively.

Professor Richard Mattessich developed the first computerized spreadsheet, which was intended for use in business accounting, in 1961. His work was documented first in a paper [2] and later in two books [3, 4]. This contribution has variously been recognized in the accounting and related literature.

In 1978, Harvard Business School student, Daniel Bricklin, pioneered the idea of an interactive visible calculator. Together with his MIT acquaintance Bob Frankston, Bricklin then invented the first known spreadsheet software named VisiCalc. In 1979, Bricklin and Frankston formed Software Arts Corporation [5].

In 1982, Lotus Development Corporation released its own spreadsheet software, Lotus 1-2-3. This new software quickly became the new industry spreadsheet standard. It made it easier to use spreadsheets and added integrated charting, plotting and database capabilities. Later, Lotus Development released another spreadsheet program: Symphony. In 1985, Lotus Development acquired Software Arts and discontinued the VisiCalc program.

Microsoft released the first version of its Excel spreadsheet program in 1985. Originally designed for the Apple Macintosh operating system, Excel used a graphical interface with pull-down menus and had support for mouse-pointing devices. This made it simpler to use than the command line interface of PC-DOS spreadsheet products. Excel was one of the first application products released for the Windows operating system launched by Microsoft in 1987.

Since the late 1980s, many companies have introduced spreadsheet products, and the spreadsheet software industry has been maturing. Many newer capabilities and functions have enriched the released spreadsheet programs and the updated versions. To date, spreadsheet programs are very numerous, some of them being commercial and some free, and exist for all computer platforms. To name only a few, we list IBM Lotus 1-2-3, Sun StarOffice Calc, Microsoft Excel, Corel Quattro Pro, Apple AppleWorks, GNOME Gnumeric, and KDE KOffice KSpread.

In a spreadsheet, spaces that hold items of data are called cells. Each cell is labeled according to its placement, as an intersection of a column and a row. Columns are labeled alphabetically and rows by numbers. For example, B3 denotes the cell in the second column and the third row. Equations are entered into cells to calculate their values based on entries in other cells. Spreadsheet programs are equipped with a rich library of built-in functions, such as mathematical and trigonometric functions, string functions, statistical functions, and logical functions. They also provide utilities to copy and/or move blocks of cells, to aid in entering the formulas and choosing their input parameters, to arrange data based on some preferences, to look up for entries, to make plots of data in specified ranges, and not last, to print the worksheet. A major attraction of spreadsheet programs, in addition to being easy to learn, is their ability to quickly answer 'What if?' questions and determine

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the outcome due to changes in the values of relevant parameters. This makes them excellent platforms for the solution of engineering-related design problems.

These features of spreadsheet programs increased their popularity and enhanced tremendously, as a result, the use of personal computers. The use of spreadsheets spread into the fields of mathematics, chemistry, physics, engineering, and many other disciplines, primarily for educational purposes. Students have little difficulty implementing algorithms in spreadsheets, allowing them to study the behavior of the resulting solutions and the performance of the algorithms without having to spend significant amounts of time writing routines that implement them.

In the next section of this paper, we review the various applications spreadsheets have in Engineering Education, especially in Control, Electronics, Electromagnetics, Circuits, Digital Systems, Neural Networks, Power, Communications and Signal Processing, Aerodynamics, Thermodynamics, and Mechanics. Also, we briefly review the spreadsheet employment in other disciplines, especially in Mathematics and Sciences. After this, we discuss possible future applications and trends of spreadsheets.

SPREADSHEETS IN ENGINEERING

Spreadsheet programs are well equipped with trigonometric, exponential and logarithmic functions, as well as with a range of arithmetic and logic operations for combining such functions. As a result, a spreadsheet is a quick and convenient way of carrying out many types of calculations that commonly occur in Electronics, Telecommunications, Signal Processing, Control, Electromagnetics, Digital Systems, and Power. In addition to their applications in electrical engineering education, spreadsheets have also witnessed numerous applications in the education of mathematics, statistics, chemistry and physics. Apart from many books on spreadsheet application in mathematics and statistics [79–81], several journal and conference papers dealt with using spreadsheets in calculus [82], as a mathematical tool [83], for teaching mathematics [84] and advanced topics in discrete mathematics [85], for visualizing correlation [86], as a model for proving combinatorial identities [87], for deciding the convergence of series [88], for simplified curve fitting [89], and lately to compute the roots of real-coefficient polynomials [90]. Spreadsheets are also used in chemistry [91–93], and in physics [94, 95].

Furthermore, the standard graphics packages provided with spreadsheets make it particularly easy to display and use the results of such calculations. Many papers point out the importance of spreadsheets in education, and especially in engineering education [6–14]. Other papers indicate more basic and discipline-independent uses of spreadsheets like course grading [15, 16], and student advising [17].

Spreadsheets in control

Spreadsheets have been extensively used to simulate and study Control Systems. In [18], El-Hajj and Kabalan employed spreadsheets to study the stability of linear control systems, and in [19] to perform the time-domain analysis of such systems. Yiu-Kwong used Symphony to calculate the frequency response of feedback control systems [20]. Stanton *et al.* [21] used spreadsheets in solving student exercises in signal and linear system analysis, and Wang *et al.* [22] used them for ramping control. In [23], Kabalan *et al.* used Lotus 1-2-3 to study the stability of an n^{th} order causal filter using Jury's method and determine whether the system is minimum-phase. The authors, in [24], used spreadsheets in the analysis of nonlinear and sampled data control systems, and in [25], Fraser uses them for control system modeling and analysis. El-Hajj *et al.* [26] presented a new method for simulating linear control systems using spreadsheet programs, which were also used to graphically simulate an analog computer [27].

Spreadsheets in electromagnetics

Spreadsheets have been used to solve a variety of problems in electromagnetics and assist electromagnetics education at the undergraduate level. In [28], they are used to compute the solution of some electrostatic boundary value problems for an introductory-level electromagnetics course, and in [29] to solve two- and three-dimensional potential problems. The authors in [30] described the use of spreadsheet programs for the numerical solution of hyperbolic partial differential equations for EM field calculations. Knox *et al.* [31] used spreadsheets to solve the wave equation with dependence on one spatial coordinate (1-D) and time. Hoeft [32] employed them to analyze reasonably complex electromagnetic coupling problems, and Shapiro [33] to solve sinusoidal steady-state transmission line and optics problems. In [34, 35], Barron proposed a method to manage the large amount of Normalized Site Attenuation (NSA) data and calculations, and implemented the theoretical NSA model using spreadsheets. He also benefited from the plotting capabilities of spreadsheet programs to graph the 3-D surface of the exact theoretical NSA calculations [36]. Spreadsheets have also been used in antenna design. Hills [37] described a method of employing spreadsheets in the design of a phased array of radiating elements. El-Hajj *et al.* [38] used them to design and analyze the uniform, binomial, and Chebyshev arrays, to plot the linear and polar array factors, and to estimate the directivity and the half-power beamwidth. Among the many other applications of spreadsheets in electromagnetics are a model design for residential magnetic field exposure [39] and RF cavity analysis [40].

Spreadsheets in communications and signal processing

The graphical display and recalculation features of spreadsheet packages, apart from their ubiquitous status and low cost, make them well suited for teaching Signal Processing and Signal Design. Spooner [41] demonstrated the usefulness of Lotus 1-2-3 as a tool for active sonar signal design. The authors of [42, 43] explored the opportunities of learning about Digital Signal Processing (DSP) using a spreadsheet. They have used an FIR digital filter as a typical example. Chapman, in [44], demonstrated the simplicity of creating discrete and fast Fourier transform (FFT) on a spreadsheet.

Spreadsheets have also been used in teaching and in dealing with some problems in communications. In [45], Anneberg *et al.* proposed a spreadsheet template that helps students visualize the error detection and correction concepts. Lallo [46] used spreadsheets to simulate and investigate data transmission over an adaptive delta modulated voice channel. The plotting capabilities of spreadsheets were exploited by Van der Valt [47] to produce a chart that is particularly useful to diagnose inter-modulation problems during the design phase of narrowband and wideband systems. Knab [48] presented a methodology whereby a spreadsheet can be easily developed to perform loading on a transponded satellite. Fiset *et al.* [49] described a spreadsheet based low-cost tool for displaying polarimetric response graphs. Spreadsheets are also extensively used by the SETI League [50] to perform some of the most common radio astronomy and SETI computations.

Spreadsheets in electronics

The use of spreadsheets has also been marked in the field of electronics. In [51], Estrada showed the ability and potential of electronic spreadsheet programs to investigate important parameters of semiconductor materials and solid-state devices by describing an academic experiment that used Lotus 1-2-3. Hartmann [52] used a spreadsheet program to automate DC calculations for single-circuit and multi-circuit networks. Rogne *et al.* [53] illustrated the use of spreadsheets as one of two efficient tools for calculating the current and temperature differences of the paralleled semiconductor chips. The authors of [54] demonstrated the use of a spreadsheet to extract the hybrid-/spl pi/ equivalent circuit of a bipolar transistor from certain measurements taken in undergraduate electronics laboratories. In [55], Forbes used spreadsheets for Fowler-Nordheim equation calculations, and in [56], Noebauer utilized the input/output capabilities and standard functions of spreadsheet programs in combination with some proposed techniques for the determination of boundary conditions independent (BCI) compact thermal models. Shapiro [57] used a spreadsheet for the numerical calculation of the potential distribution in a pn diode that can be included in an introductory course in semiconductor devices.

Spreadsheets in circuits and digital systems

An attractive feature of spreadsheets is the presence of the logical and trigonometric functions, making them very suitable for circuits and digital design education. Svoboda [58] showed that spreadsheet programs can be used to introduce practical considerations in introductory electrical engineering courses, such as predicting and/or minimizing the errors due to loading, the availability of only standard resistance values, and to resistor tolerances. El-Hajj and Kabalan [59] presented a spreadsheet tool for the analysis, design, and test of combinational, sequential, synchronous, and asynchronous logic networks in educational environments. In [60], El-Hajj and Hazim presented an improved and user-friendlier spreadsheet method for the simulation of logic networks based on simulating the basic blocks that constitute a logic network and connecting these blocks together. Saul [61] described the use of a spreadsheet as a tool for mixed analog and digital designs and as a means of visualizing the effects of a range of design decisions. El-Hajj *et al.* presented a spreadsheet simulation of a range of digital integrated circuits for a course on logic design [62].

More advanced uses of spreadsheets have been witnessed in the field of computer engineering. Foster [63] used spreadsheets in the analysis of packaging-related aspects of bus delay as part of a devised technique to optimize bus performance early in the design cycle. In [64], El-Hajj *et al.* employed spreadsheets in a microprocessor simulation, and in [65], the authors used them as an educational tool for microprocessor systems. Diab [66] described the usage of Lotus 1-2-3 to study the behavior of the cache miss ratio and the bus bandwidth with respect to the cache line size in a cache-based multiprocessor system. El-Hajj *et al.* [67] presented a spreadsheet method for simulating the step-by-step program execution inside a Z80 microprocessor.

Spreadsheets in neural networks

'A spreadsheet contains several thousands cells, arranged in rows and columns, appearing to perform in parallel. The numerical values of certain cells (i.e. their outputs) become parameters for calculating the values of others linked to them via suitable formulas'. This is very similar to a neural network, which 'consists of many simple computational units, highly interconnected and operating in parallel. Each unit has a numerical value (an output), which it communicates to other units along connections of varying strength'. Walter and McMillan [68] advocated these similarities and presented a unified framework and method for studying small neural networks (up to 75 neurons) using a computer spreadsheet. Antonini [69] showed the usefulness and simplicity of spreadsheets as a tool for prototyping, studying, and simulating neural networks. In [70], Bemley used spreadsheets for teaching neural networks to pre-college students.

Spreadsheets in power

Spreadsheets have also made their way into power engineering. Rao and Haddad [71] used Lotus 1-2-3 to solve core power system problems developed in the context of the Power Engineering Curriculum at the University of Calgary. In [72], Morley *et al.* presented a procedure for applying circuit-analysis techniques to perform non-iterative power system analysis using a spreadsheet. Chaaban *et al.* [73] provided an analytical method for simulating polyphase induction motors, generators and transmission line performance using spreadsheet programs for organizing, analyzing and presenting data. The authors of [74] employed spreadsheets as a platform for power system load flow, fault and harmonic analysis that has been used to solve real engineering problems as well as to teach university students.

Other applications of spreadsheets are in aerodynamics: to solve fluid dynamics problems for an aeronautical course [75], and to model turbojet performance [76], in mechanics: to analyze fluid mechanics problems [77], and in thermodynamics: to implement a numerical solution for two-dimensional heat flow through a fin [78].

CONCLUSION AND FUTURE TRENDS

The ubiquity and simplicity of spreadsheet programs, in addition to their rich library of built-in functions, plotting capabilities, and other provided utilities, have made them an attractive tool for education in engineering and other disciplines. The continuous improvements, in the computational complexity of computer systems, are allowing the spreadsheet software industry to provide constantly spreadsheet programs that are more sophisticated. More and more features are added to spreadsheets to make them more useful and hence giving way for an even larger number of applications to be developed. The abundance of computer resources and the increasing efficiency of spreadsheet programs in using these resources enable larger and more complex problems to be dealt with using spreadsheets. Besides, newer applications are being made possible with the introduction of add-ins features that are integrated within spreadsheets to extend their capabilities.

This paper presented a brief description of the history of spreadsheets development, and reviewed various applications spreadsheets have in electrical engineering education, especially in control, electromagnetics, communications and signal processing, electronics, circuits and digital systems, neural networks, power systems, and other fields. Spreadsheet employment in mathematics and other sciences was quickly reviewed, and possible future trends and applications were also considered.

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